บทวิทยาการ
Original Article

กำลังยึดติดแบบเฉือนของระบบสารยึดติดที่ต่างชนิดกัน เมื่อใช้ยึดแบร็กเกตจัดฟันกับพื้นผิวพอร์ซเลน

Shear Bond Strength of Different Adhesive Systems for Bonding Orthodontic Brackets to Porcelain Surfaces

เรือนแก้ว ทีปกานนท์[1], วิรัช พัฒนาภรณ์[2], ศิริพงศ์ ศิริมงคลวัฒนะ[3]
[1]นักศึกษาหลังปริญญาสาขาทันตกรรมจัดฟัน ภาควิชาทันตกรรมจัดฟันและทันตกรรมสำหรับเด็ก คณะทันตแพทยศาสตร์มหาวิทยาลัยเชียงใหม่
[2]ภาควิชาทันตกรรมจัดฟันและทันตกรรมสำหรับเด็ก คณะทันตแพทยศาสตร์ มหาวิทยาลัยเชียงใหม่
[3]ภาควิชาทันตกรรมบูรณะและปริทันตวิทยา คณะทันตแพทยศาสตร์ มหาวิทยาลัยเชียงใหม่
Ruankaew Teepaganont[1], Virush Patanaporn[2], Siripong Sirimongkolwattana[3]
[1]Postgraduate student in Orthodontics, Department of Orthodontics and Pediatric Dentistry, Faculty of Dentistry, Chiang Mai University
[2]Department of Orthodontics and Pediatric Dentistry, Faculty of Dentistry, Chiang Mai University
[3]Department of Restorative Dentistry and Periodontology, Faculty of Dentistry, Chiang Mai University

ชม.ทันตสาร 2553; 31(2) : 87-95
CM Dent J 2010; 31(2) : 87-95

บทคัดย่อ

วัตถุประสงค์ของงานวิจัยนี้เพื่อวัดและเปรียบเทียบกำลังยึดติดแบบเฉือนของระบบสารยึดติดห้าชนิดเมื่อใช้ยึดแบร็กเกตจัดฟันกับพื้นผิวพอร์ซเลนรวมทั้งวิเคราะห์ตำแหน่งความล้มเหลวของการยึดติด กลุ่มที่ 1 ใช้กรดไฮโดรฟลูอริกความเข้มข้นร้อยละ 9.6 กลุ่มที่ 2 และ 4 ใช้กรดฟอสฟอริกความเข้มข้นร้อยละ 37 ร่วมกับไซเลน กลุ่มที่ 3 และ 5 ใช้กรดไฮโดรฟลูอริกความเข้มร้อยละ 9.6 ร่วมกับไซเลน โดยกลุ่มที่ 1, 2 และ 3 ใช้ซิสเทมวันพลัสและกลุ่มที่ 4 และ 5 ใช้ซุปเปอร์บอนด์ซีแอนด์บีเป็นวัสดุยึดติด ทดสอบกำลังยึดติดแบบเฉือน

Abstract

The aims of this study were to measure and compare the effects of five different adhesive systems on the shear bond strength of orthodontic brackets bonded to porcelain surfaces and to analyze the modes of bond failure after de-bonding the brackets. One hundred porcelain cylindrical disks were divided into five groups. The orthodontic brackets were bonded to the porcelain using five different adhesive systems: Group I, etching with 9.6%

Corresponding Author:

วิรัช พัฒนาภรณ์
รองศาสตราจารย์ ภาควิชาทันตกรรมจัดฟันและทันตกรรมสำหรับเด็ก คณะทันตแพทยศาสตร์ มหาวิทยาลัยเชียงใหม่ เชียงใหม่ 50202

Virush Patanaporn
Associate Professor, Department of Orthodontics and Pediatric Dentistry, Faculty of Dentistry, Chiang Mai University, Chiang Mai 50202
E-Mail: dnoti003@chiangmai.ac.th

ด้วยเครื่องทดสอบแรงแบบอเนกประสงค์ พบค่าเฉลี่ยกำลังยึดติดแบบเฉือนของแต่ละกลุ่มเท่ากับ 10.9, 18.5, 20.7, 23.7 และ 27.6 เมกกะพาสคาลตามลำดับ เมื่อวิเคราะห์ทางสถิติด้วยการวิเคราะห์ความแปรปรวนแบบทางเดียว พบว่ากลุ่มที่ 1 มีค่าเฉลี่ยกำลังยึดติดแบบเฉือนต่ำที่สุดและแตกต่างกับกลุ่มอื่นอย่างมีนัยสำคัญทางสถิติ ($p < 0.05$) กลุ่มที่ 2, 3 และ 4 มีค่าเฉลี่ยกำลังยึดติดแบบเฉือนไม่แตกต่างกันอย่างมีนัยสำคัญทางสถิติ ($p > 0.05$) โดยกลุ่มที่ 5 แสดงค่าเฉลี่ยกำลังยึดติดแบบเฉือนสูงที่สุดและแตกต่างกับกลุ่มที่ 1, 2 และ 3 อย่างมีนัยสำคัญทางสถิติ ($p < 0.05$) ลักษณะความล้มเหลวของกลุ่มที่1พบความล้มเหลวของการยึดติดที่ระหว่างผิวพอร์ซเลนกับแอดฮีซีฟเป็นส่วนใหญ่ (ร้อยละ 65) ในขณะที่กลุ่มที่เหลือพบความล้มเหลวของการยึดติดหลายรูปแบบไม่เด่นชัด กลุ่มที่ 2, 3, 4 และ 5 พบบางชิ้นงานที่มีการแตกหักของพอร์ซเลน

คำสำคัญ: กำลังยึดติดแบบเฉือน ระบบสารยึดติด พอร์ซเลนทางทันตกรรม แบร็กเกตทางทันตกรรมจัดฟัน

hydrofluoric acid; Groups II and IV, etching with 37% phosphoric acid followed by Silane; Groups III and V, etching with 9.6% hydrofluoric acid followed by silane. Specimens in Groups I, II and III were bonded with System1™ + and those in Groups IV and V with Super-Bond C&B. The shear bond strength was then tested using a universal testing machine. The mean shear bond strength values in Groups I to V were 10.9, 18.5, 20.7, 23.7 and 27.6 MPa, respectively. All data were analyzed using an analysis of variance. The lowest mean shear bond strength was in Group I and was significantly different ($p < 0.05$) from that in the other groups. There was no significant difference between the mean shear bond strength values in Groups II, III and IV ($p > 0.05$). Group V had the highest mean shear bond strength and was significantly different from that in Groups I, II and III ($p < 0.05$). The porcelain/adhesive interface was the commonest site of failure in Group I (65%), whereas the failure sites in the other groups showed mixed types of bond failure with no specific location predominating. Some damaged porcelain surfaces were found in Groups II, III, IV and V.

Keywords: shear bond strength, adhesive systems, dental porcelain, orthodontic bracket

Introduction

Dental porcelain is a popular restorative material. The difficulty that orthodontists face when they treat patients with porcelain restorations is that the conventional bonding procedure is not possible.[1,2] In previous studies, different methods and combinations of methods have been recommended.[2-9] Mechanical roughening of the surface with diamond burs and sandblasting are reported to provoke cracks within the ceramic.[2,10] Chemical conditioning with hydrofluoric acid also has been recommended to bond brackets to the porcelain surfaces.[11-16] Organosilane coupling agents also have been recommended to increase the bond strength of brackets bonded to porcelain surfaces.[2,4] Although various surface treatment methods have been recommended, each has some disadvantages and limitations. The purposes of this study were to measure and compare the shear bond strength values of five different adhesive systems when used to bond orthodontic metal brackets to porcelain surfaces and to describe the modes of bond failure after de-bonding the brackets.

Materials and Methods

Porcelain cylindrical disks, 10 mm in diameter and 5 mm in thickness, were prepared from conventional feldspathic porcelain (Vita porcelain powders, Bad Säkingen, Germany) according to the manufacturer's recommendations by a skilled ceramic technician. The porcelain specimens were fixed in stainless steel rings with self curing acrylic resin to obtain stability during the bond strength tests. The specimens were randomly distributed to five test groups (Table 1) (N=20 for each group). The orthodontic brackets were bonded to the porcelain using five different adhesive systems: Group I, etching with 9.6% hydrofluoric acid; Group II, etching with 37% phosphoric acid followed by silane; Group III, etching with 9.6% hydrofluoric acid followed by silane; Group IV, etching with 37% phosphoric acid followed by silane; and Group V, etching with 9.6% hydrofluoric acid followed by silane. The etching time used in this study was 60 seconds for both hydrofluoric acid and phosphoric acid. The silane agent used in this study was Porcelain liner M (Sun Medical Co., Ltd., Shiga, Japan). Specimens in Groups I, II and III were bonded with System™1+ (Ormco Corporation, Orange, California, USA) and those in Groups IV and V with Super-Bond C&B (Sun Medical Co., Ltd., Shiga, Japan) (Table 2). All specimens were stored in distilled water at 37°C for 24 hours and then subjected to

Table 1 *Five groups of adhesive systems and materials used in this study*

ตารางที่ 1 *ระบบสารยึดติดและวัสดุที่ใช้ในการทดสอบห้ากลุ่ม*

Group	Acid etching	Silane	Adhesive
Group I	9.6% Hydrofluoric acid	-	System™1+
Group II	37% phosphoric acid	Porcelain liner M	System™1+
Group III	9.6% Hydrofluoric acid	Porcelain liner M	System™1+
Group IV	37% phosphoric acid	Porcelain liner M	Super-Bond C&B
Group V	9.6% Hydrofluoric acid	Porcelain liner M	Super-Bond C&B

Table 2 *Material used in this study*

ตารางที่ 2 *วัสดุที่ใช้ในการทดลอง*

Material	Application	Composition	Manufacturer
Phosphoric acid Etching Solution	Etch surface for 60 s, rinse and air dry	37% Phosphoric acid solution	Ormco Corporation (California, USA)
Hydrofluoric acid Porcelain etch gel	Etch surface for 60 s, whip with cotton, rinse and air dry	9.6% Hydrofluoric acid gel	PULPDENT Corporation (Massachusetts, USA)
Silane agent Porcelain liner M	Mix liquid A and B, apply one coat and blow lightly	Organosilane, 4-META, MMA	Sun Medical Co., Ltd. (Shiga, Japan)
Self-cured adhesive resin System™1+	Apply liquid component on bracket base and specimen, apply paste on bracket base	Urethane modified dimethacrylate	Ormco Corporation (California, USA)
Self-cured adhesive cement Super-Bond C&B	Mix liquid and powder with brush dip technique, apply on bracket base	Polymethyl methacrylate, 4-META, MMA, Partly oxidized TBB	Sun Medical Co., Ltd. (Shiga, Japan)

thermocycling between 5±2°C and 55±2°C for 1000 cycles. The shear bond strength was then tested using a universal testing machine (Instron Calibration Laboratory, Norwood, Massachusetts, USA) at a 0.5 mm/min crosshead speed. The values of highest shear bond strength at bond failure were recorded.

After de-bonding, failure sites were determined by examination of the de-bonded bracket surfaces from pictures scanned with a 1200 dpi scanner. A computerized transparent grid was placed on the pictures and the amounts of residual adhesives on the de-bonded bracket surfaces were determined and converted to residual adhesive per total de-bonded porcelain surface. A modified Adhesive Remnant Index (ARI) was used to evaluate the amount of adhesive left on the porcelain sample.(13,14,17) Visual inspections of all de-bonded porcelain surfaces were carried out and the specimens with visible porcelain surface damaged were assigned a score of 4.

Modified Adhesive Remnant Index (ARI):

Score 0 = No adhesive left on the porcelain surface

Score 1 = Less than half the adhesive left on the porcelain surface

Score 2 = More than half the adhesive left on the porcelain surface

Score 3 = All the adhesive left on the porcelain surface, with a distinct impression of the bracket mesh

Score 4 = Damage to the porcelain sample

Statistical analyses

One way analysis of variance (ANOVA) was used to compare the mean shear bond strength values among five different adhesive systems. A multiple comparisons test (Tukey's test) was used to identify which values were significantly different among the five different adhesive systems. The Kruskal -Wallis test was used to analyze the ARI score.

Results

The mean shear bond strength values in Groups I to V were 10.9, 18.5, 20.7, 23.7 and 27.6 MPa, respectively. One way analysis of variance (ANOVA), revealed a statistically significant difference in the mean shear bond strength values among the five different adhesive systems. The results of a multiple comparisons test (Tukey's test) (Figure 1) showed that the lowest mean shear bond strength was in Group I and was significantly different ($p < 0.05$) from that in the other groups. There was no significant difference between the mean shear bond strength values in Groups II, III and IV ($p > 0.05$). This study showed that Group V had the highest mean shear bond strength for bonding orthodontic brackets to porcelain surfaces and was significantly different ($p < 0.05$) from that in Groups I, II and III.

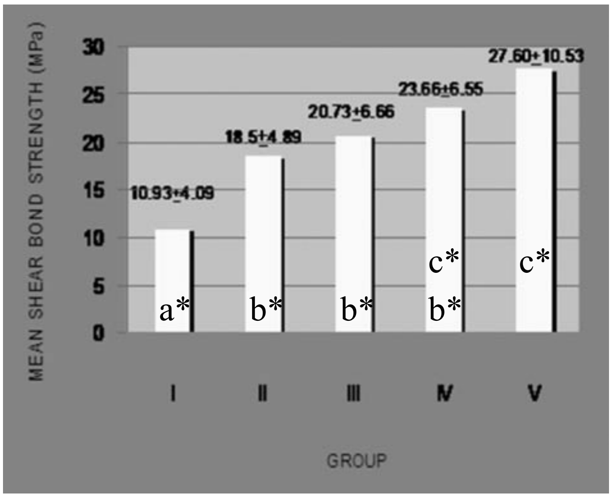
Data for the Adhesive Remnant Index are shown in Table 3. The Kruskal -Wallis test revealed that the mean ranks of ARI scores of the five groups were significantly different ($P < 0.001$). The porcelain/resin interface was the commonest site of failure in Group I (65%), whereas the failure sites in the other groups showed mixed types of bond failure, with no specific location predominating, and with some or all of the adhesive left on the porcelain surfaces (ARI scores 2 or 3). Some damaged porcelain surfaces were found in Groups II, III, IV and V, but not in Group I, particularly in the specimens that were bonded with Super-Bond C&B (Groups IV and V), which had 30% and 45% damaged surfaces, respectively.

Discussion

It has been suggested by Reynolds(18) that clinically adequate bond strength for a metal orthodontic bracket bonded to enamel is 6 to 8 MPa. The mean shear bond strength values of

Figure 1 *Histogram of the mean and standard deviations of shear bond strengths values of the five groups of adhesive systems*

รูปที่ 1 *แผนภูมิแสดงค่าเฉลี่ยและส่วนเบี่ยงเบนมาตรฐานของกำลังยึดติดต่อแรงเฉือนของระบบสารยึดติดทั้งห้ากลุ่ม*



**Bars with the same letter are not significantly different (p > 0.05) from each other*

**แผนภูมิแท่งที่อักษรตัวเดียวกันไม่มีความแตกต่างกันอย่างมีนัยสำคัญทางสถิติ (p > 0.05)*

Table 3 *The ARI scores and percentages of the five groups of adhesive systems*

ตารางที่ 3 *ค่าคะแนนและค่าร้อยละของคะแนนเออาร์ไอของระบบสารยึดติด 5 กลุ่ม*

ARI Group	0	1	2	3	4	Total
I	13 65%	7 35%	0 0%	0 0%	0 0%	20
II	0 0%	6 30%	6 30%	5 25%	3 15%	20
III	0 0%	3 15%	10 50%	4 20%	3 15%	20
IV	1 5%	0 0%	8 40%	5 25%	6 30%	20
V	1 5%	3 15%	3 15%	4 20%	9 45%	20
Total	15	19	27	18	21	100

metal brackets bonded to ceramic surfaces in this study showed mean values which were all greater than those required for minimal orthodontic forces and, therefore, can be considered sufficient for clinical application.

In this study hydrofluoric acid was used because its efficiency in improving the bond strength of brackets bonded to ceramics has been widely accepted.[4,7,8,13-16] Wolf[19] reported that a hydrofluoric acid etching time longer than 60 seconds increased cohesive failures in porcelain when de-bonding. For this reason, the etching time in this study was reduced to 60 seconds. In this study, Group I, where the porcelain surfaces were etched with hydrofluoric acid alone, showed the lowest, but acceptable, mean shear bond strength. Although the mean shear bond strength obtained with hydrofluoric acid etching was satisfactory, there are some disadvantages to using hydrofluoric acid. Extreme care should be taken during intraoral application of hydrofluoric acid because contact between the acid and soft tissues can cause severe tissue irritation, thus requiring bonding separately from other teeth, with careful isolation of the working area.[1,20]

It has been previously proved that phosphoric acid is relatively ineffective for providing mechanical retention on porcelain.[19] Silane provides a chemical link between dental porcelain and composite resin, and the organic portion of the molecule increases the wettability of the porcelain surface, thereby providing a closer micromechanical bond.[2,21] However, disagreement exists concerning the effectiveness of organophosphoric acid with silane application. The issue of bond reliability using organosilanes has been of concern. Some studies show that application of silane alone did not give sufficient bond strength to withstand occlusal force and that the silane coating should be combined with surface roughening or hydrofluoric acid etching.[4,7,9,13,15,16,21-24] However in this study, the use of silanes without hydrofluoric acid etching (Group II) demonstrated an acceptable mean shear bond strength value. This finding confirms the option for using silane to improve bond strength to porcelain, a conclusion that is in keeping with the findings of other authors.(2,10,19,20,25-27) Although hydrofluoric acid etching with silane application (Group III) resulted in increased bond strength, that value was not significantly different from that of the group subjected to organophosphoric acid and silane (Group II).

In this study, System™1+ and Super-Bond C&B were used. System™1+ is a diacrylate resin, based on the acrylic modified epoxy resin, bis-GMA. Super-Bond C&B is a 4-methacryloxyethyl trimellitate anhydride (4-META)/methyl methacrylate adhesive resin cement that has been used for bonding orthodontic brackets and has earned a reputation for strong bonding.(28) The 4-META functions as a coupling agent, promoting adhesion to composite resins, enamel, dental alloys and ceramic powders.(29,30) The groups in which the brackets were bonded with Super-Bond C&B showed significantly higher mean shear bond strength values than did those in which the brackets were bonded with System™1+ when each adhesive was used only with hydrofluoric acid and silane surface preparation. There was no significant difference in mean shear bond strength value when each adhesive was used with phosphosic acid and silane surface preparation. Although Super-Bond C&B showed markedly high shear bond strength, more destruction of porcelain surfaces also occurred than with System™1+. Moreover, another drawback of Super-Bond C&B was that the application (brush dip technique) was more complicated than that for commonly-used adhesive resin.

After completion of orthodontic treatment, the porcelain restorations generally remain in the mouth after de-bonding. Therefore, an important requirement in bracket bonding to porcelain is that there should be no damage to the porcelain surface after de-bonding. In Group I of this study, adhesive failures were most frequently seen between the porcelain and composite resin. This type of adhesive failure demonstrated that the strength of the bond between the adhesive and the bracket and the cohesive strength of the composite were greater than that of the bond between the adhesive and the porcelain.

In general, increased bond strength between the adhesive resin and porcelain surface resulted in failures within the resin or resin/ bracket base so that some resin was left on the bracket or the ceramic surfaces. The residual composite on porcelain surfaces can then be removed with an adhesive removal tool or a low-speed finishing bur.(21) Cohesive failure in the ceramic material could indicate that the bond between the adhesive resin and the porcelain was stronger than the porcelain itself. On de-bonding, the different adhesive systems showed different percentages of damaged porcelain surfaces. Some previous studies found more fracture sites within the porcelain when silane was used.(11,27,31) In this study, some damaged porcelain surfaces were found in Groups II, III, IV and V, but not in Group I (no silane application).

Even though the incidence of cohesive ceramic fractures has been found to be excessively high in laboratory testing,(8,10) the incidence of ceramic damage in clinical practice while de-bonding brackets has been stated to be very low, or not to occur at all.(5) The reason for this discrepancy might be that clinically, proper and safe de-bonding techniques are used, with adequate peeling forces, which are different from the techniques and forces used in shear testing in the laboratory.[8,12] The shear force is thought to be a risk factor for porcelain destruction, and, therefore, bracket removal by applying tensile forces is desirable.[31,32] However, the possibility of porcelain fractures cannot be excluded. Therefore, orthodontists should inform patients about this risk and that they may need a new prosthesis. In order to avoid the risk of destroying prostheses during bracket removal, the use of appropriate removal procedures and the use of adhesive systems with less risk of porcelain destruction are necessary. Groups II, III, IV and V had some specimens with porcelain surface fractures, but not Group I. Therefore, the suggested system for use in clinical practice is 9.6% hydrofluoric acid etching for 60 seconds before bonding with System™1+.

Conclusions

1. The mean shear bond strength values in Groups I to V were 10.9, 18.5, 20.7, 23.7 and 27.6 MPa, respectively. All groups in this study showed mean shear bond strength values which were greater than those required for optimal orthodontics forces and, therefore, can be considered sufficient for clinical application.

2. The porcelain/adhesive interface was the commonest site of failure in Group I, whereas the failure sites in the other groups showed mixed types of bond failure with no specific location predominating. Some damaged porcelain surfaces were found in Groups II, III, IV and V

3. Within the limitations of this study, the suggested system for use in clinical practice is 9.6% hydrofluoric acid etching for 60 seconds before bonding with System™1+.

Acknowledgement

The authors wish to thank Dr. M. Kevin O Carroll, Professor Emeritus of the University of Mississippi School of Dentistry, USA, and Faculty Consultant at Chiang Mai University Faculty of Dentistry, Thailand, for his assistance in the preparation of the manuscript.

References

1. Graber TM, Vanarsdall RL, Vig KWL. *Orthodontics: current principles & techniques*. 4th ed., St. Louis, Mo.: Elsevier Mosby, 2005: 579-659.
2. Kocadereli I, Canay S, Akca K. Tensile bond strength of ceramic orthodontic brackets bonded to porcelain surfaces. *Am J Orthod Dentofacial Orthop* 2001;119:617-620.
3. Major PW, Koehler JR, Manning KE. 24-hour shear bond strength of metal orthodontic brackets bonded to porcelain using various adhesion promoters. *Am J Orthod Dentofacial Orthop* 1995;108:322-329.
4. Barbosa VL, Almeida MA, Chevitarese O, Keith O. Direct bonding to porcelain. *Am J Orthod Dentofacial Orthop* 1995;107:159-164.
5. Zachrisson BU. Orthodontic bonding to artificial tooth surfaces: clinical versus laboratory findings. *Am J Orthod Dentofacial Orthop* 2000;117:592-594.
6. Chung CH, Brendlinger EJ, Brendlinger DL, Bernal V, Mante FK. Shear bond strengths of two resin-modified glass ionomer cements to porcelain. *Am J Orthod Dentofacial Orthop* 1999;115:533-535.
7. Turkkahraman H, Kucukesmen HC. Porcelain surface-conditioning techniques and the shear bond strength of ceramic brackets. *Eur J Orthod* 2006;28:440-443.
8. Gillis I, Redlich M. The effect of different porcelain conditioning techniques on shear bond strength of stainless steel brackets. *Am J Orthod Dentofacial Orthop* 1998;114:387-392.

9. Turk T, Sarac D, Sarac YS, Elekdag-Turk S. Effects of surface conditioning on bond strength of metal brackets to all-ceramic surfaces. *Eur J Orthod* 2006;28:450-456.
10. Nebbe B, Stein E. Orthodontic brackets bonded to glazed and deglazed porcelain surfaces. *Am J Orthod Dentofacial Orthop* 1996;109:431-436.
11. Cochran D, O'Keefe KL, Turner DT, Powers JM. Bond strength of orthodontic composite cement to treated porcelain. *Am J Orthod Dentofacial Orthop* 1997;111:297-300.
12. Schmage P, Nergiz I, Herrmann W, Ozcan M. Influence of various surface-conditioning methods on the bond strength of metal brackets to ceramic surfaces. *Am J Orthod Dentofacial Orthop* 2003;123:540-546.
13. Ozcan M, Vallittu PK, Peltomaki T, Huysmans MC, Kalk W. Bonding polycarbonate brackets to ceramic: effects of substrate treatment on bond strength. *Am J Orthod Dentofacial Orthop* 2004;126:220-227.
14. Karan S, Buyukyilmaz T, Toroglu MS. Orthodontic bonding to several ceramic surfaces: are there acceptable alternatives to conventional methods? *Am J Orthod Dento-facial Orthop* 2007;132:144 e147-114.
15. Huang TH, Kao CT. The shear bond strength of composite brackets on porcelain teeth. *Eur J Orthod* 2001;23:433-439.
16. Harari D, Shapira-Davis S, Gillis I, Roman I, Redlich M. Tensile bond strength of ceramic brackets bonded to porcelain facets. *Am J Orthod Dentofacial Orthop* 2003;123:551-554.
17. Artun J, Bergland S. Clinical trials with crystal growth conditioning as an alternative to acid-etch enamel pretreatment. *Am J Orthod* 1984;85:333-340.
18. Reynolds IR, von Fraunhofer JA. Direct bonding of orthodontic attachments to teeth: the relation of adhesive bond strength to gauze mesh size. *Br J Orthod* 1976;3:91-95.
19. Wolf DM, Powers JM, O'Keefe KL. Bond strength of composite to etched and sandblasted porcelain. *Am J Dent* 1993;6:155-158.
20. Bourke BM, Rock WP. Factors affecting the shear bond strength of orthodontic brackets to porcelain. *Br J Orthod* 1999;26:285-290.
21. Ajlouni R, Bishara SE, Oonsombat C, Soliman M, Laffoon J. The effect of porcelain surface conditioning on bonding orthodontic brackets. *Angle Orthod* 2005;75:858-864.
22. Zachrisson YO, Zachrisson BU, Buyukyilmaz T. Surface preparation for orthodontic bonding to porcelain. *Am J Orthod Dentofacial Orthop* 1996;109:420-430.
23. Pannes DD, Bailey DK, Thompson JY, Pietz DM. Orthodontic bonding to porcelain: a comparison of bonding systems. *J Prosthet Dent* 2003;89:66-69.
24. Kern M, Thompson VP. Sandblasting and silica coating of a glass-infiltrated alumina ceramic: volume loss, morphology, and changes in the surface composition. *J Prosthet Dent* 1994;71:453-461.
25. Larmour CJ, Bateman G, Stirrups DR. An investigation into the bonding of orthodontic attachments to porcelain. *Eur J Orthod* 2006; 28:74-77.
26. Sant'Anna EF, Monnerat ME, Chevitarese O, Stuani MB. Bonding brackets to porcelain--in vitro study. *Braz Dent J* 2002;13:191-196.
27. Newman SM, Dressler KB, Grenadier MR. Direct bonding of orthodontic brackets to esthetic restorative materials using a silane. *Am J Orthod* 1984;86:503-506.

28. Kawasaki M, Hayakawa T, Takizawa T, Sirirungrojying S, Saitoh K, Kasai K. Assessing the performance of a methyl methacrylate-based resin cement with self-etching primer for bonding orthodontic brackets. *Angle Orthod* 2003;73:702-709.
29. Sperber RL, Watson PA, Rossouw PE, Sectakof PA. Adhesion of bonded orthodontic attachments to dental amalgam: In vitro study. Am J Orthod Dentofacial Orthop 1999; 116:506-513.
30. McSherry PF. An in vitro evaluation of the tensile and shear strengths of four adhesives used in orthodontics. *Eur J Orthod* 1996; 18:319-327.
31. Andreasen GF, Stieg MA. Bonding and debonding brackets to porcelain and gold. *Am J Orthod Dentofacial Orthop* 1988;93:341-345.
32. Kitayama Y, Komori A, Nakahara R. Tensile and shear bond strength of resin-reinforced glass ionomer cement to glazed porcelain. *Angle Orthod* 2003;73:451-456.